ALTERNATIVE FUELS: ARE WE MAKING THE RIGHT CHOICES?

SSCF Independent Research Project
(DAU Research Report SSCF-MW 08-4)

Todd P. Weimer

May 2008

Submitted to Lawrence Technological University in partial fulfillment of the degree of Master of Science in Global Leadership and Management

Submitted to Defense Acquisition University in partial fulfillment of the requirements of the Senior Service College Fellowship Program

Report Documentation Page			*Form Approved OMB No. 0704-0188*
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.			
1. REPORT DATE **01 MAY 2008**	2. REPORT TYPE **N/A**		3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Alternative Fuels: Are we Making the Right Choices? SSCF Independent Research Project (DAU Research Report SSCF-MW 08-4)**			5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Todd P. Weimer**			5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000**			8. PERFORMING ORGANIZATION REPORT NUMBER **18801**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S) **TACOM/TARDEC** 11. SPONSOR/MONITOR'S REPORT NUMBER(S) **18801**
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**			
13. SUPPLEMENTARY NOTES **Submitted to Lawrence Technological University in partial fulfillment of the degree of Master of Science in Global Leadership and Management Submitted to Defense Acquisition University in partial fulfillment of the requirements of the Senior Service College Fellowship Program, The original document contains color images.**			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**41**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

DISCLAIMER

ALTERNATIVE FUELS: ARE WE MAKING THE RIGHT CHOICES?

SSCF Independent Research Project
(DAU Research Report SSCF-MW 08-4)

Todd P. Weimer

May 2008

Submitted to Lawrence Technological University in partial fulfillment of the degree of Master of Science in Global Leadership and Management

Submitted to Defense Acquisition University in partial fulfillment of the requirements of the Senior Service College Fellowship Program

TABLE OF CONTENTS

ABSTRACT

Our world is dependent on fossil fuels, and so is our military. As discovery of oil has slowed, our demand has increased. How long before the world's reserves will be exhausted depends on who is asked. What alternative fuel is the solution to our impending dilemma depends on the research scientists. The choices they make affect us all. But what considerations are factored into making these decisions? The choices the research scientists make can impact the Army both economically and operationally. This paper seeks to identify some key considerations when selecting an alternative fuel. The paper compares the choices of the research scientists to Army logisticians. Differences of considerations may affect the Army's long-term operations.

EXECUTIVE SUMMARY

TACOM is responsible for fielding and supporting one of the largest ground combat forces in the world. One of the key elements to supporting this large mechanized force is fuel—currently fossil fuel. The continued use of fossil fuel is a worldwide concern. The concern stems from both availability and environmental impact. Research scientists everywhere are developing alternative energy sources, including alterative fuels for use in automobiles.

The choices these research scientists make could have a huge impact on how TACOM, or the Army, conducts and supports military operations, so it is important to understand the decision process. This research evaluated the factors the research scientists felt were most important and then compared these rankings to those of TACOM's logisticians. A divergence of importance could indicate that the research scientists' decisions might lead to large, wholesale changes for our combat and tactical systems and may even have changed how we conduct operations.

The results did not show a divergence of decision-making factors. This is encouraging and should indicate that changing to a replacement fuel should be a smooth transition. The research also indicates that initial transition for the commercial consumer could be as soon as 5 years. This relatively quick transition may prompt a transition of the government beyond what has already taken place in the General Service Administration (GSA) fleet.

Lastly, it is not a question of *if* the Army converts to an alternative fuel. It is a question of *when*. The research was clear that fossil fuels may not last into the next century. TACOM may be forced to follow commercial industry in their choice of alternative fuels. This is why it is important to understand the decisions being made, as they could impact our future warfighters.

CHAPTER 1
INTRODUCTION

Alternative Fuels

Fossil fuels will not last forever, and their continued use adversely affects our environment. Based on one estimate by the National Center for Policy Analysis, it is estimated that the world's oil reserves could be depleted as early as 2056 (Deming, 2003). A more conservative estimate takes into consideration that in 2000 there were estimated to be 3,000 billion barrels of oil in reserves to be produced (USGS, 2000). At a world consumption rate of 83 million barrels per day (Bb/d) (Energy Information Administration [EIA], 2007) the world's reserves would be exhausted in 99 years. The same EIA report suggests reserves are only at 1,317 billion barrels and predicts global consumption in 2015 to be 97 million barrels per day. At this pessimistic rate, the world's reserves would last approximately 37 more years. It is highly doubtful that the latter will occur, but even so, it is not a question of *if* we convert to an alternative fuel, but a question of *when* we convert.

Then there is the issue of fossil fuel emissions' contribution to global warming. Global warming has been on the political agenda for more than a decade, and President George W. Bush wishes to reduce both our dependence on foreign oils and the emissions. Today's research scientists in the field are looking for the elusive green or alternative fuel that can be produced cheaply and in sufficient quantities to meet today's market consumption, and that produces zero greenhouse gas emissions. It is also important to provide ample energy output. The logistician and the warfighter would prefer a replacement fuel that would cause no impact to current operations when implemented. This research paper will briefly discuss the types of alternative fuels currently available and analyze what researchers and logisticians consider important when considering replacement fuels.

Background

In 2006, President George W. Bush signed the National Security Policy stating that "our comprehensive energy strategy puts a priority on reducing our reliance on foreign energy sources" (Bush, 2006). Further, the Department of Defense (DoD) Energy Security Task Force is chartered with "defining an investment roadmap for lowering DoD's fossil fuel requirements and for identifying alternate energy sources" (http://proceedings.ndia.org/jsem2007/Shaffer.pdf). To support these national objectives, TACOM Life Cycle Management Command (LCMC) needs to be aware of the current state of technology, how the technology supports the DoD mission and the President's strategy, and how the options would impact the warfighter.

The Army has also set up a strategy to push toward environmental sustainability. Under the definition of the Army's "Strategy for the Environment" (2004), "a sustainable Army simultaneously meets current as well as future mission requirements worldwide, safeguards human health, improves quality of life, and enhances the natural environment." The Army understands the importance of our environment. To develop an environmentally friendly alternative energy source to replace our fossil fuel-burning combat and support systems is one of the keys to supporting that strategy.

Key leaders within TACOM LCMC were asked to provide research topics for the Senior Service College Fellowship program. The topic of this research paper has a direct relational impact on the systems managed by TACOM and supports both the President's and the Army's strategies.

TACOM LCMC has responsibility over a large fleet of fuel-burning equipment, from the M1 Abrams Main Battle Tank to water purification systems. TACOM has Army responsibility for ground combat vehicles, ground tactical vehicles, and ground support vehicles. Because of the tremendous amount of equipment supported by TACOM LCMC, any fuel change that requires system changes could conceivably have a significant impact on operations across the LCMC. The largest impacts could be realized in logistics. How a new fuel is handled and delivered on the battle field could change our operations and current equipment. The change could also impact the soldier in how he or she directly handles the alternative fuel on the battle field.

Problem Statement

Are research scientists considering the potential impacts to the logistical infrastructure when developing possible alternative fuels or energy sources? Which considerations do they feel are most important in the continuation of research? Are those considerations in line with what the logisticians feel are important? A divergence of thought between the needs of the logisticians and the research scientists could have a large impact to both the warfighter and the logistician. While this research may not be conclusive, it should provide some insight into the current thinking of the different constituents.

Purpose of the Study

The main purpose of the research is to support one of the Army's top three priorities: sustainability. The Army is leading the charge in sustainability and understands the importance of protecting the environment. Without the needed changes, DoD and the Army will continue to pollute the environment, consume the remaining reserves of fossil fuels, and possibly jeopardize the strength of our nation.

This research will also support DoD's Energy Task Force charter and will support the President's desire to reduce environmental pollution. The President also desires to reduce our dependence on foreign oils; changing to an alternative energy source may all but eliminate this dependence.

This research paper will briefly summarize current green and alternative fuels that could support both DoD and the President's strategy. The research will identify considerations that the research scientists feel are most important and if these considerations are consistent with the goals of the logistician. These considerations also need to support the government's policies and support the development of fuels which minimize the negative impact on the war fighter.

Limitation to this Study

This research surveyed only logisticians who currently work for TACOM's Integrated Logistics Support Center (ILSC), including individuals from the Army's Petroleum Center. The results

represent only the organizations within the federal government that also support fuel-burning systems. The short time to conduct the research was also a limitation. The survey on which the research is partly based received a relatively small number of responses from research scientists.

CHAPTER 2
LITERATURE REVIEW

Introduction to Fuels

There are many organizations conducting research of alternative fuels: National Renewable Energy Lab (NREL), Golden, CO; GreenFuel Technologies, Cambridge, MA; Energy & Environmental Research Center, University of North Dakota; British Petroleum via Energy Biosciences Institute, University of Illinois, IL and UC Berkeley, CA; and Oakridge National Laboratory, Oak Ridge, TN.

Researchers are investigating renewable fuels, alternative fuels, and green fuels. What differentiates these fuels from each other? Alternative fuels are fuel "sources that are other than those derived from fossil fuels" and renewable energy is "energy resources that are naturally replenishing but flow-limited" (Department of the Interior, 2007). It is harder to find a clear definition of "green." According to the organization Green Technology, "the field of 'green technology' encompasses a continuously evolving group of methods and materials, from techniques for generating energy to non-toxic cleaning products" (www.green-technology.org/what.htm). Green fuels are a type of alternative fuel, so for the purposes of this paper, the term "alternative" will be used to represent all types of fuels other than fossil fuels.

Alternative Fuels

The following are different alternative fuels currently being researched as replacements for fossil fuels in the internal combustion engine.

> **Liquefied petroleum gas** (LPG), better known as propane, is a clean-burning fossil fuel that can be used to power internal combustion engines. LPG-fueled vehicles produce fewer toxic and smog-forming air pollutants. LPG is usually less expensive than gasoline, and most LPG used in the United States comes from domestic sources. (U.S. Department of Energy, 2007)
>
> **Ethanol** is an alcohol-based fuel made by fermenting and distilling starch crops, such as corn. It can also be made from "cellulosic biomass" such as trees and grasses. The use of ethanol can reduce our dependence upon foreign oil and reduce greenhouse gas emissions. (U.S. Department of Energy, 2007)
>
> **Natural gas**, a fossil fuel composed mostly of methane, is one of the cleanest-burning alternative fuels. It can be used in the form of **compressed natural gas** (CNG) or **liquefied natural gas** (LNG) to fuel cars and trucks. (U.S. Department of Energy, 2007)
>
> **Biodiesel** is a form of diesel fuel manufactured from vegetable oils, animal fats, or recycled restaurant greases. It is safe, biodegradable, and produces fewer air pollutants than petroleum-based diesel. (U.S. Department of Energy, 2007)

Hydrogen (H2) is being aggressively explored as a fuel for passenger vehicles. It can be used in fuel cells to power electric motors or burned in internal combustion engines. It is an environmentally friendly fuel that has the potential to dramatically reduce our dependence on foreign oil, but several significant challenges must be overcome before it can be widely used. (U.S. Department of Energy, 2007)

Methanol, also known as wood alcohol, can be used as an alternative fuel in flexible fuel vehicles that run on M85 (a blend of 85 percent methanol and 15 percent gasoline). Methanol is not commonly used because automakers have begun to focus more on ethanol based flex fuel vehicles. (E85.whipnet.net, 2007)

Fischer-Tropsch technology converts coal, natural gas, and low-value refinery products into a high-value, clean-burning fuel. The resultant fuel is colorless, odorless, and low in toxicity. In addition, it is virtually interchangeable with conventional diesel fuels and can be blended with diesel at any ratio with little to no modification. (U.S. Environmental Protection Agency, 2002)

Homogeneous charge compression ignition (HCCI) engines have the potential to provide high, diesel-like efficiencies and very low emissions. In an HCCI engine, a dilute, premixed fuel/air charge auto ignites and burns volumetrically as a result of being compressed by the piston. The charge is made dilute either by being very lean or by mixing with recycled exhaust gases. (Sandia Corporation, 2006)

Each one of these has advantages and disadvantages as a fossil fuel replacement. Disadvantages range from unsafe storage to limited amount of storage, and advantages range from minimal emissions to none at all (at source of usage). A quick Internet search will lead to multiple hits on the current state of each of these technologies. The research is not only United States-based; Denmark, Brazil, Japan, and many other countries are also researching alternative fuels. The world's consumption of fossil fuel is continually increasing, albeit at reduced rates from those of the early 1990s, when the prices of fuel were more conducive to consumption (E.I.A 2008). The continued consumption drives escalating depletion of the world's reserves. There is a finite amount of fossil fuel in the world. At the world's current rate of consumption the remaining amount may not last until the turn of the next century.

Which of these alternative fuels is preferable depends on many variables. For example, consider biodiesel. The current production capability of the plants operational today in the United States is 2.24 billion gallons of biodiesel (National Biodiesel Board, 2008). This is almost 50 percent of the 4.5 billion gallons that DoD consumed in FY 2000 (Office of the Inspector General, 2002). This is 33 percent less than the FY 2005 consumption of 6.88 billion gallons, which includes consumption in the operations in Iraq and Afghanistan (CRS, 2007). One research study estimated that by 2030, the United States could possibly be producing 60 billion gallons of biodiesel per year (De La Torre Ugarte, English, Jensen, 2007). The study showed that production at that level was only able to meet 14.4 percent of the United States' estimated 2005 consumption of 20.8 million Bb/d. Even at this production level, there was an impact on the cost of feed grain (CIA, 2007).

MacLean and Lave Study, 2002

A 2002 study in gathered information from multiple studies of alternative fuels for automobiles, including reformulated fuels, CNG, methanol, ethanol, LPG, LNG, Fischer-Tropsch, electrical, and hydrogen sources. The authors thought that only those could be produced in quantities to power a significant portion of the fleet of personal transportation. The study looked at the performance, the environmental impact (emission and raw material gathering), and the cost of each fuel; and if they were in development at the time. Each of these considerations is important in choosing an alternative fuel.

When everything was considered as stated above, there was no one fuel that met or satisfied all the requirements at current production. There was no evidence provided to indicate whether production could be increased to meet demand. The study made assumptions on the social issue of preferences over sources and vehicles, as well as the safety of utilizing each of the materials. This results in further division of possible wholesale solutions using any one fuel. The report was detailed, with an abundance of information on most of the alternative solutions. The results of the study lead one to understand where we are today. What the study did not address was the resulting infrastructure changes if we were to change to one of these alternative fuels.

Current Build-up

Some of the alternative fuels are making their way into the market. There are varying numbers of filling stations around the United States to support these fuel alternatives as shown in Table 1.

	BD	CNG	E85	ELEC	HY	LNG	LPG	Totals
Totals by Fuel:	651	790	1,348	435	33	35	2,290	5,582

CNG-Compressed Natural Gas, E85-85 percent Ethanol, LPG-Propane,
ELEC-Electric, BD-Biodiesel, HY-Hydrogen and LNG-Liquefied Natural Gas
(www.eere.energy.gov/afdc/fuels/stations_counts.html) As of 02/06/2008

Table 1. Number of Alternative Fueling Stations by Fuel Type

These are small numbers when compared to the 121,446 gasoline filling stations in the United States in 2002 (U.S. Census Bureau, 2002). While the distribution point is a key aspect, the infrastructure needed to support the filling stations is another issue. According to the Department of Energy, over 200,000 miles of pipeline in the United States support the filling stations at a capital cost investment of $31 billion in 2007 dollars. There are also issues with utilizing the current infrastructure to distribute the alternative fuels, some of which cannot be transported with the existing U.S. infrastructure (Hicks, 2007).

Even with the build-up of stations throughout the United States to support these types of alternative fuels, many do not visualize any of these as a solution. William Clay Ford, Jr., Chairman of Ford Motor Corporation, addressed the University of Michigan's School of Natural Resources and Environment voicing frustration over the current state of research. "We always knew that food-

based ethanol would not be the answer," Ford stated. His frustration was not just with the pollutants from automobiles, but also with the suggestion that the world population of cars would grow from 880 million cars currently to 2 billion by 2050 (Maynard, 2007). Aside from considerations like emissions, raw material, and the cost of fuel, the total quantity of vehicles outside DoD is also a huge consideration when looking at alternative fuels.

The Changeover

In the search for an alternative fuel, there are a myriad of issues which must be addressed along the way of development. The researcher must consider the status of the resources from which the fuel will be produced. Material choice should reflect sound judgment on hazards, availability, life, and manufacturability of the material. Social and cultural implications must be considered as well as laws and regulations. Efficiency of manufacturing, distribution and recycling are key considerations. The developers also have to consider the disposition after the useful life. All these are important considerations in industrial ecology when developing an alternative fuel (Graedel, Allenby, 2003).

While there is a considerable amount of research going on for the alternative fuel, very little research is ongoing to determine the magnitude of impacts to the logistical infrastructure. Carnegie Mellon's Civil and Environmental Engineering College had this to say in a brochure promoting their research projects:

> **Infrastructure Requirements of Alternative Fuels**. This interdisciplinary project is developing models to consider the economic and environmental burdens of emerging alternative fuel pathways, such as hydrogen, ethanol, and plug-hybrid vehicles. This project combines work on the impacts of producing the fuels with analysis of the amounts and impacts of the infrastructure needed to deliver the energy to the consumer. This is important because much existing research neglects infrastructure impacts. (EESM, 2007)

It is important to note the last statement: "existing research neglects infrastructure impacts." An extensive review of publications, journals, papers, and other informational documents through the Lawrence Technological University Library services confirmed this statement. Of the few studies found, two directly related to hydrogen will be discussed here: Moore and Raman (1998); and Chang, Li, Gao, Huang, and Ni. (2006).

The Moore and Raman study looked at the building of the production facility, storage, transportation, distribution facilities and equipment. In its conclusion, the cost of hydrogen fuel ranged from \$2.30 to \$3.30 per kilogram at the wholesale level in 1998. A kilogram of hydrogen is equivalent in energy comparison to a gallon of gasoline. The average cost of a gallon of gasoline in 1999 was \$1.25. There was no distinction in the price as to whether hydrogen would be stored on the vehicle in gas or liquid phase. To convert hydrogen to liquid for transport is another increase in cost. Each phase, gas or liquid, has a slight impact on how the infrastructure needs to be developed stating that current infrastructure supports the transportation of hydrogen in a liquid state (Moore and Raman, 1998).

The Chang, Li, Gao, Huang, and Ni study looked at the Life Cycle Analysis (LCA) prospect of developing an infrastructure for hydrogen in Beijing, China. Where the Moore and Raman study noted only that a difference in cost would be realized between transporting hydrogen in liquid or gas form, this study identified the distance from manufacturing plant to the distribution point as a variable to be considered in determining if gas or liquid phase would be cost-effective. This study also estimated that the cost of hydrogen in Beijing would be approximately $1.85 per kg in 2005 (Chang, Li, Gao, Huang, and Ni, 2006).

A third study by Ogden, Steinbugler, and Kreutz (1998) considered the implications of converting the vehicles and infrastructure to use hydrogen or methanol or gasoline for the fuel in hybrid fuel cell vehicles. The study amortized the cost to convert the infrastructure over the total number of vehicles. This was done for each fuel source: gasoline, hydrogen, and methanol. The results of the study projected that the cost of just converting the car to use methanol-powered fuel cell was $500 to $600 per car *more* than the comparable hydrogen fuel cell vehicle. And the cost of a gasoline-powered fuel cell was $800 to $1200 per car *more* than the comparable hydrogen fuel cell vehicle. The study also estimated the capital cost of the infrastructure development for hydrogen would be $310 to $620 per car, depending on the type of hydrogen (liquid or gas). The study accounted for some existing methanol facilities. The researchers assumed that the cost to convert would initially be around $50 per vehicle and would increase to about $330 to $770 per vehicle once full demand was reached. They assumed no cost to convert the infrastructure for a gasoline-powered fuel cell.

The Consideration

Combine the fuel usage of the military services and the usage of the Pentagon, and the total usage becomes the single largest consumer of fossil fuels in the United States (Karbuz, 2007). For the Army, the conversion to an alternative fuel could be painful and costly. Like the commercial infrastructure, the conversion may take 10 to 20 years, but the driving consideration is not time. Considerations are the cost to convert each vehicle system to the replacement alternative fuel and the cost to convert the distribution equipment. The training and safe handling is another consideration. Availability is also a key consideration for the Army. Lastly, meeting the policies set by the President and DoD are important considerations.

Looking at the research on alternative fuels, a usual metric is a price comparison to the cost of a gallon of gas. Can we produce this fuel in sufficient quantities at comparable prices? As the price per barrel goes up, some of these technologies, as well as others that are less known, become more viable. While it is apparent that the researcher is looking at the bottom dollar with allowable resources, it is important to ensure that the Life Cycle Analysis (LCA) of each fuel is conducted. The entire industrial ecology must be considered. In particular, the impact to the logistical footprint of the U.S. Army has to be considered, not just the price.

CHAPTER 3
METHODOLOGY

Survey to Research Scientists

A tool was needed in order to assess what considerations research scientists felt were most important in selecting technologies to pursue for alternative fuels. To that end, a survey was developed to address three main areas. The first area was general information on which type of alternative fuel the scientists are currently focused on. The second area gathered their thoughts on the specific impacts (positive and/or negative) their alternative fuel would have to the military's logistics. The third area gathered information specifically on the considerations the scientists felt were important when selecting a technology to develop.

The survey was developed using a Web-based program for both ease of design and ease of use by the research scientists. The Web-based survey allowed for the e-mailing of the survey to specific addresses. This allowed the research scientists to complete the survey at their convenience. The survey instructed respondents to complete the survey for each type of alternative fuel they were developing. Of 35 specific e-mails sent, there were 23 completed surveys by 19 individuals. The questions contained in the survey were determined based on the literature review as well as input from subject matter experts from TACOM LCMC. Once the survey was developed, it was sent in draft form internally to select individuals along with senior leaders within the TACOM LCMC community. Leaders were asked to have the survey reviewed by their engineers/scientists and provide comments. The results of the pilot survey helped to refine and further define the questions. The final product contained 15 questions, with two questions containing additional sub-questions (15 sub-questions). All questions were open-ended; respondents answered only the questions they felt at liberty to answer. Question 15 asked that the respondents rank order the importance of considerations. The rank order was not forced, and the respondent could place the same level of importance on all considerations, even though the survey requested they did not. The research scientists' survey can be seen in Appendix A.

While the survey was being developed, a list of contacts (those who would receive the survey) was created. TACOM LCMC experts were contacted to obtain industry contacts, and a Web search was conducted to find contacts in the United Kingdom, Denmark, Japan, as well as other research organizations within the United States, such as the Department of Energy (DOE). Once individuals were identified and the survey was finalized, each received an e-mail asking that they fill out the survey as well as provide it to other known research scientists to complete. Between January 21 and 23, 2008, e-mails were sent to each identified respondent. A follow-up friendly reminder e-mail was sent out a week later. Of the 36 researchers contacted, there were 23 responses from 19 respondents. There were multiple responses from research scientists who were working on several different types of alternative fuels.

Survey to Logisticians

In order to identify considerations the logisticians felt would be most important in choosing a technology if they had the opportunity, the research scientists' survey was modified to include

only the considerations portion of the survey. Another Web-based survey site was chosen that also allowed for e-mailing of the survey to specific addresses. Once the survey was completed a pilot survey was also conducted and sent to expert logisticians for review. The pilot survey resulted in no changes to the draft. The final survey was sent to TACOM's ILSC director on January 28, 2008. It was requested that the ILSC director send the survey to the logistics employees working in supply. This one e-mail generated 156 responses across TACOM LCMC. This survey contained 11 considerations, which the respondents were asked to rank order by importance. The rank order was not forced and respondents could identify each consideration as important, even though the survey encouraged them not to. The logistician survey can be seen in Appendix B.

Limitations

The research paper is limited on the number of researchers contacted as well as the number who responded to the survey. Several e-mail communications with contacts within the fuels research community elicited the information that they are constantly bombarded with surveys, and there is no guarantee the researchers will actually complete a provided survey. Also, with the very limited amount of time to identify researchers for each type of green or alternative fuel, it is realistic to say that globally, this paper contacted a very minor portion of the researchers with knowledge to participate in the surveys; however, a response rate of 54 percent of those research scientists contacted is very good.

This paper limited the logisticians' survey to those individuals who work supply for the TACOM LCMC. While the results may not reflect all of Army or DoD, it is anticipated that the results will represent their views because TACOM provides and supports all of the Army's mobility platforms, representing a majority of the individuals who would be impacted directly if a new fuel were introduced into the Army.

Analysis

All responses from both surveys were collect by the online Web-based survey site. Each site provided tools that allow for easy filtering to do comparative analysis of the collected responses.

CHAPTER 4
RESULTS

Research Scientists

A total of 23 complete surveys were received from research scientists from different areas of research, including those working on biodiesels, methanol, Fischer-Tropsch, and a few others. No surveys were received from research scientists working in the areas of LPG, CNG, LNG, electric storage, or the homogeneous charge compression ignition systems. A majority of the surveys received were from research scientists working in the Bio (8) and the Fischer-Tropsch (6) areas.

Based on the results of the survey, the research scientists appear to be aware of the political policies driving the United States toward an alternative fuel. Of the respondents, 88 percent were aware of the President's National Security Strategy, which puts "a priority on reducing our reliance on foreign energy sources." Also, 76 percent of research scientists indicated being aware of the Energy Security Task Force, which is chartered with "defining an investment roadmap for lowering DoD's fossil fuel requirements and for identifying alternate energy sources" (http://proceedings.ndia.org/jsem2007/Shaffer.pdf).

The technology under development by the responding research scientists varied in the degree of technology readiness level (TRL). The research scientists responded with TRLs ranging from TRL-2 (Fischer-Tropsch) to TRL-8 (other). The research scientists provided different responses for similar technologies. For example, research scientists varied their opinions of the state of Bio-fuel development at TRL-4 and TRL-5, with a majority responding at TRL-4. TRL-4 is defined as follows: "a low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments and associated performance predications are defined relative to the final operating environment" (NASA, 2007). Each research scientist responded that the energy balance of his or her technology was either 1 or less than 1. Energy balance is defined as the amount of energy required to produce an amount of the technology, compared to the energy required to produce an amount of fossil fuel for the same energy output of both. The scientists' responses indicate that less energy is required to produce their technology than to produce an equivalent amount of fossil fuel for the same output. One research scientist responded that fossil fuel was not used in the manufacturing of his technology, indicating that the question may not have been clearly enough stated in the survey.

A majority of the research scientists (79 percent) indicated that the technologies they are working on were intended to be used by the automotive industry, and 68 percent indicated that their technology could be used for jet propulsion or power generation. The technologies of the respondents will be ready for integration for these intended uses in 1 to 5 years as indicated by 22 of the responses, with 17 responses indicating that the technologies could be ready in 3 to 5 years. The research scientists all agreed that of the technologies to be ready in 3 to 5 years, each of the identified technologies could be available in a shorter time frame with additional funding. The amount of additional funding needed was stated as a percentage of the current funding level. The amount of additional funding ranged from 50 percent to 1,000 percent of current funding. One research

scientist responded that the timeline would be difficult to compress because of the amount of testing required, and that testing represented majority of the development time. Another research scientist responded that market acceptance delays the timeline for mainstream integration. Still another research scientist responded that a technology breakthrough was needed to assist in advancing the timeline of integration.

Only one technology was indicated to have any negative impact on the U.S. military's logistics. A research scientist who is working on the development of dimethyl ether indicated that there was a low negative impact to the military systems used for storage of and systems used for transport of the current diesel/JP-8. The research scientist further indicated that this technology had no impact on the current design of the combat and tactical vehicle systems and a low positive impact to the fuel distribution equipment. Most research scientists indicated that their technology had no impact to each of the four areas (fuel storage equipment, fuel transport equipment, fuel distribution equipment, and combat/tactical systems).

There were 11 factors presented to the research scientists to rank in order of importance when considering an alternative fuel. Each factor could be marked as *most important*, *important*, *somewhat important*, and *least important*.

1. Cost
2. Ease of use
3. Reduce dependence on foreign supplies
4. Provides a tactical advantage
5. Environmentally Friendly
6. Safer than traditional fuels
7. Easier to transport than traditional fuels
8. Easier to store than traditional fuels
9. Storage life (capable of storing for long periods of time)
10. Availability
11. Complexity of training in the use, handling, and storage

The research scientists were not forced to rank-order but were encouraged to do so. Table 1 summarizes how the research scientists ranked the factors. As is evident, reducing dependence on foreign supplies and availability of the sources were the most significant factors to the research scientists when considering alternative fuels, reinforcing the fact that most research scientists indicated awareness of the President's strategy to reduce dependence on foreign oil. The research scientists are also aware of the large volume of fuel to be consumed, not only by the government, but throughout the United States. The cost and ease of use were also important factors considered by the research scientists. The intended market for their research is the U.S. consumer. Any type of alternative fuel will need to be relative in cost to the fossil fuels. For example, if a consumer can drive to work and back all week on $40-worth of regular gasoline, he or she would expect to pay a very similar cost for the alternative fuel. The consumer will also want the same convenience in buying alternative fuel as pulling up to a gas pump.

ALL RESPONSES FROM SCIENTISTS	Most Important	Important	Somewhat Important
FACTORS			
Cost	17.00%	65.00%	17.00%
Ease of Use	35.00%	65.00%	0.00%
Reduce dependence on Foreign Supplies	61.00%	26.00%	13.00%
Provides a Tactical Advantage	9.00%	43.00%	39.00%
Environmentally Friendly	9.00%	48.00%	39.00%
Safer Than Traditional Fuels	0.00%	13.00%	52.00%
Easier to Transport than Traditional Fuels	9.00%	17.00%	17.00%
Easier to Store than Traditional Fuels	4.00%	17.00%	17.00%
Storage Life	17.00%	26.00%	57.00%
Availability	57.00%	43.00%	0.00%
Complexity of Training	9.00%	52.00%	30.00%

Table 2. Data from all the Research Scientists

Transportation and storage of the alternative fuel were ranked the least important factors by the research scientists. The alternative fuel will be used to power commuter vehicles. The research scientists are concerned with storage for these smaller vehicles. It would be safe to assume that transportation on larger vehicles in volumes would not be an issue then. The reason for storage to be ranked so low could follow the same reasoning.

Other analyses were conducted with the data, such as comparing responses by alternative fuel research types, knowledge of DoD's and the President's strategies, and TRLs. Nothing significant was found to report.

Logisticians

The logisticians' survey was a reduced form of the research scientists' survey as discussed in Chapter 3. The logisticians were asked to respond only to the ranking of factors. The survey then asked them to indicate their years of logistical experience and if they worked directly with fuel supply equipment. Two distinct groups were queried for response: TACOM-Warren, MI, and the Army's Petroleum Center (APC).

Table 2 summarizes the ranking of factors from the logisticians from TACOM-Warren. The responses are centered on the *most important* and *important* choices. Respondents ranked many factors to be *most important* and *important* while considering very few to be only *somewhat important* and *least important*. Still the logisticians at Warren clearly identified that two factors most important in their view: to reduce dependence on foreign supplies and fuel availability. The two least important factors were storage of the alternative fuel and transportation of the alternative fuel.

ALL LOGISTICIAN RESPONSES TACOM-Warren	Most Important	Important	Somewhat Important	Least Important
FACTORS				
Cost	31.10%	51.40%	14.90%	2.70%
Ease of Use	22.40%	57.10%	18.40%	2.00%
Reduce dependence on Foreign Supplies	54.10%	34.50%	8.10%	3.40%
Provides a Tactical Advantage	30.90%	51.00%	14.10%	4.00%
Environmentally Friendly	36.70%	40.70%	18.00%	4.70%
Safer Than Traditional Fuels	22.30%	48.60%	23.60%	5.40%
Easier to Transport than Traditional Fuels	15.30%	44.00%	32.00%	8.70%
Easier to Store than Traditional Fuels	12.20%	43.20%	35.80%	8.80%
Storage Life	11.40%	49.70%	29.50%	9.40%
Availability	65.30%	32.00%	2.70%	0.00%
Complexity of Training	10.10%	53.70%	26.80%	9.40%

Table 3. Summary of Responses TACOM-Warren Logisticians

The logisticians are fully aware of the need for fuel on the battlefield. Availability of fuel for the warfighter is a major contributor to winning wars. The logistician may also be looking at the term "availability" as meaning global availability, where the research scientists may look at the term "availability" only domestically. This point was identified by a senior logistician after the surveys were completed. A difference of view from respondents could impact the results of the surveys.

The Army Petroleum Center (APC) also participated in the survey. While there were only a few respondents (five in total), this group of people work directly with fuel-related equipment. Their responses support those rankings made by the Warren respondents. There was nothing significantly different in their responses (see Table 4).

ALL RESPONSES ARMY PETROLEUM CENTER	Most Important	Important	Somewhat Important	Least Important
FACTORS				
Cost	0.00%	0.00%	60.00%	40.00%
Ease of Use	40.00%	40.00%	20.00%	0.00%
Reduce dependence on Foreign Supplies	0.00%	60.00%	40.00%	0.00%
Provides a Tactical Advantage	20.00%	60.00%	20.00%	0.00%
Environmentally Friendly	0.00%	40.00%	40.00%	20.00%
Safer Than Traditional Fuels	0.00%	0.00%	100.00%	0.00%
Easier to Transport than Traditional Fuels	0.00%	20.00%	40.00%	40.00%
Easier to Store than Traditional Fuels	0.00%	40.00%	60.00%	0.00%
Storage Life	0.00%	100.00%	0.00%	0.00%
Availability	100.00%	0.00%	0.00%	0.00%
Complexity of Training	0.00%	40.00%	0.00%	60.00%

Table 4. Summary Army Petroleum Center Logisticians Only

Looking more closely at the responses from TACOM-Warren, there is a distinct bimodal distribution of years of experience that is identified in the data. Of the 150 responses, 56 respondents had 1 to 5 years of experience and 62 respondents had 21+ years of experience, see Table 5. There was an almost even distribution of respondents between these two distinct groups. This indicates that there may be a large turn over of knowledge in the near future at TACOM Warren.

Experience Level	1-5 Years	6-10 Years	11-20 Years	21 or More
Percentage	39.20% (56)	9.10% (13)	8.40% (12)	43.40% (62)

Table 5. Summary TACOM-Warren Years of Experience

Several other analyses were conducted on the data from Warren Logisticians. The data was analyzed for differences by age or working directly or indirectly with fuel equipment. The only difference worth mentioning from the data had to do with the factor of environmentally friendly. Respondents with fewer years experience ranked this factor higher by almost 20 percent than those with 21 years of experience. This difference may be attributed to the younger generation's being more environmentally conscious. The correlation between the less experienced group and more senior group on all but environmental friendliness may be an indication that the transfer of knowledge between these two groups is very successful.

Scientists and Logisticians

Table 6 provides for a side-by-side comparison of the rank order of the two groups, research scientists and logisticians. The only noticeable difference between the two rankings is in the factors of cost and environmentally friendly. Despite the fact that the less experienced of the logisticians ranked the factor of "environmentally friendly" higher, the total responses of the logicians ranked this factor lower than did the research scientists. The Army's priority of sustainability, which was discussed in the earlier chapters, may not have made as much of an impact on the senior logisticians as it appears to have made on the junior logisticians. Also, cost was ranked lower by the logisticians than the research scientists. This difference results from different customers for the two groups. The research scientists' ultimate consumers are the millions of people at the fuel pumps. High costs would severely hamper acceptance of the alternative fuel by the consumer. For the logisticians, the consumer is the soldier in the field. The cost of the fuel is important to the taxpayer but not at the expense of the ability to complete the mission by the warfighter.

FACTORS	Research Scientists	Logisticians
Reduce dependence on Foreign Supplies	1	2
Availability	2	1
Cost	3	5
Ease of Use	3	3
Complexity of Training	5	4
Environmentally Friendly	6	9
Provides a Tactical Advantage	7	6
Storage Life	8	7
Safer Than Traditional Fuels	9	8
Easier to Store than Traditional Fuels	10	10
Easier to Transport than Traditional Fuels	11	11

Table 6. Comparison of Rank Order of Importance

CHAPTER 5
CONCLUSION

There are many factors guiding our choices from day to day. Not all factors are important to everyone, yet some affect us all. The research scientists are making choices now that will affect us all for years to come. This study considered a small sample of research scientists who were attempting to provide an alternative to our dependence on foreign oils and fossil fuels. Based on the responses from the research scientists, it appears the goals set forth by the President and other branches of our government were being heard.

Of the factors identified to the research scientists and logisticians, there does not appear to be a discrepancy in the important factors that would significantly affect the Army. This research indicates that the choices research scientists are making are in line with the majority of logisticians surveyed. This appears to hold somewhat true regardless of how the data for the logisticians are sorted. The results from research scientists are not completely conclusive, and a different or larger sample of respondents might yield different results. With more time, a greater number of research scientists could be contacted to conduct a more thorough analysis.

The factors presented are not all that could be considered for this research. Perhaps a short interview with some key leaders in each of the alternative research areas would present a different or a more inclusive set of factors to add to the survey. This, along with a forced ranking of the factors, could possibly improve the quality of the data. This would definitely alleviate how the data from the TACOM-Warren logisticians was heavily centered on *important*. Also, definition of each factor should be provided. As stated in the analysis, different views of the terms could have resulted in different outcomes.

While it does appear that the efforts of the research scientists will lead to solutions that have little to no impact on the military, what should be clear to everyone is the relatively short time until the change to an alternative fuel will be made. Fossil fuels have been in demand for only the last century and a half. The world may very well consume the earth's remaining reserves within this century.

It is recommended that a more thorough research of the factors be conducted in 3 to 5 years, by which time the current technology will have matured to the point that the factors affecting it can be examined. It may also allow for the inclusion of research scientists in areas that were not part of this research paper. The elapsed time may also see the change in the logisticians as the older workforce retires. This may impact the ranking of factors amongst the logisticians. Though, it is anticipated that the rankings will change very little over this time period.

The Army will be converting to an alternative fuel, possibly in this century. It is important for the Army to monitor the choices research scientist have and make for developing alternative fuels, since these choices could have a huge impact to the way the Army does business.

APPENDIX A
SURVEY TO RESEARCHERS

Green/Alternative Fuels for Combat, Tactical and Support Vehicles

1. Please tell us who you are, who you work for, and how to contact you.
   Name:
   Company:
   Address:
   Phone:

2. Are you aware of The United States of America's National Security Strategy, March 2006, which states, "Our comprehensive energy strategy puts a priority on reducing our reliance on foreign energy sources"?
   http://www.whitehouse.gov/nsc/nss/2006/nss2006.pdf
   - Yes
   - No

3. Are you aware of the Department of Defense (DoD) Energy Security Task Force who is charted with "…defining an investment roadmap for lowering DoD's fossil fuel requirements and for identifying alternate energy sources"?
   http://www.dod.mil/ddre/energy/text_version.html
   - Yes
   - No

4. What type of green/alternative fuel technology are you/your agency developing?
   - Liquefied Petroleum Gas (LPG)
   - Compressed Natural Gas (CNG)
   - Liquefied Natural Gas (LNG)
   - Methanol (M85)
   - Ethanol (E85)
   - Biodiesel (B20)
   - Electrical Storage
   - Hydrogen
   - Homogeneous Charge Compression Ignition
   - Fischer-Tropsch
   - Other (please specify)

5. Please identify the Technology Readiness Level (TRL) of your fuel technology in its current state.

   For TRL definitions:
   http://www.sbir.nasa.gov/SBIR/sbirsttr2007/solicitation/appendix_B.pdf

6. Please indicate the approximate energy balance of your fuel as a ratio of the amount of fossil fuel energy used to make the fuel.
   Fossil fuel energy input: 1.0

7. Please indicate the amount of greenhouse emissions produced by your fuel (total for production and use).

   Units need to be in lbs/gal, if not, please indicate units used.

8. Please indicate where the raw materials for your fuel originate.
   - Domestic (US and its territories)
   - Other (please specify)

9. Please indicate the intended application of your technology. (check all that apply)
   - Automotive
   - Rail
   - Marine
   - Jet Propulsion
   - Power Generation
   - Other (please specify)

10. Given the current state of development for your green/alternative fuel technology, please indicate when the technology is planned to be fully matured.
    - 1-2 years
    - 3-5 years
    - 6-10 years
    - Beyond 10 years

11. If additional funds were identified (above that currently planned), the timeline for integration of the technology could accelerate by:
    - 1-3 years sooner
    - 4-7 years sooner
    - 8-10 years sooner
    - Other (please specify)

12. As a percentage, approximately how much additional funding would be required to accelerate as you have indicated above?

13. If no amount of funding would accelerate the timeline, could you please explain why?

14. Please indicate how your specific technology would impact the US Military's logistics for transporting, distribution, and storage of fuel on the battlefield.

		High Impact-Negative	**Medium Impact-Negative**	**Low Impact-Negative**	**No Impact**	**Low Impact-Positive**	**Medium Impact-Positive**	**High Impact-Positive**
	a. How much of an impact will your technology have on the current systems utilized to store diesel/JP-8 at a supply depot?	○	○	○	○	○	○	○
	b. How much of an impact will your technology have on the current systems utilized to transport diesel/JP-8 to the battlefield?	○	○	○	○	○	○	○
	c. How much of an impact will your technology have on the current design of combat and tactical vehicle fuel systems?	○	○	○	○	○	○	○
	d. How much of an impact will your technology have on the distribution equipment currently utilized by the Military?	○	○	○	○	○	○	○

15. In general for any type of technology, which of the following do you believe are the most or least
important considerations for the use of green/alternative fuels. While most are important, please
try and rank order your answers.

		Most Important	Important	Somewhat Important	Least Important
	Cost	○	○	○	○
	Ease of use	○	○	○	○
	Reduce dependence on foreign supplies	○	○	○	○
	Provides a tactical advantage	○	○	○	○
	Environmentally friendly	○	○	○	○
	Safer than traditional fuels	○	○	○	○
	Easier to transport than traditional fuels	○	○	○	○
	Easier to store than traditional fuels	○	○	○	○
	Storage life (capable of storing for long periods of time)	○	○	○	○
	Availability	○	○	○	○
	Complexity of training in the use, handling, and storage	○	○	○	○

Submit

APPENDIX B
SURVEY TO LOGISTICIANS

Today's researchers are developing clean or alternative fuels in an effort to reduce the United State's dependency on foreign oils. Some researchers are even looking at alternative energies, such as fuel cells, for mobile power generation. What do you feel are the most and least important consideration when choosing a fuel technology to be integrated into the Army's mobility platforms?

While most of these considerations are important, please try and rank order your answers.

	Most Important	Important	Somewhat	Important	Least Important
Cost	❍	❍	❍	❍	❍
Ease of use	❍	❍	❍	❍	❍
Reduce dependence on foreign supplies	❍	❍	❍	❍	❍
Provides a tactical advantage	❍	❍	❍	❍	❍
Environmentally friendly	❍	❍	❍	❍	❍
Safer than traditional fuels	❍	❍	❍	❍	❍
Easier to transport than traditional fuels	❍	❍	❍	❍	❍
Easier to store than traditional fuels	❍	❍	❍	❍	❍
Shelf life	❍	❍	❍	❍	❍
Availability	❍	❍	❍	❍	❍
Complexity of training in the use, handling, and storage	❍	❍	❍	❍	❍

How many years of experience with supply do you have?

	1-5	6-10	11-20	21 or more
Years	❍	❍	❍	❍

Do you work directly with fuel storage / distribution equipment?

❍ Yes ❍ No

REFERENCES

Alternative Fueling Station Total Counts by State and Fuel Type. (2008, 6 February). Washington, DC; U.S. Department of Energy. Retrieved February 16, 2008, from <www.eere.energy.gov/afdc/fuels/stations_counts.html>.

Bush, G. (2006). The National Security Strategy. Washington DC. The White House.

Central Intelligence Agency, (2008, February 7). Retrieved February 8, 2008, from The World Factbook Web site: <https://www.cia.gov/library/publications/the-world-factbook/geos/us.html>.

Chang, L., Li, Z., Gao, D., Huang, H., & Ni, W. (2007, November). Pathways for hydrogen infrastructure development in China: Integrated assessment for vehicle fuels and a case study of Beijing. ScienceDirect, 32, Issue 11, 2023-2037.

CRS Report for Congress. (2007). The Department of Defense: Reducing its Reliance on Fossil-Based Aviation Fuel-Issues for Congress (RL34062). Washington, DC: Government Printing Office.

De La Torre Ugarte, D., English, B., Jensen, K. 2007. Sixty Billion Gallons by 2030: Economic and Agricultural Impacts of Ethanol and Biodiesel Expansion. American Agricultural Economics Association: Knoxville, TN.

Deming, D. (2003, 29 January). Are we Running out of Oil?..National Center for Policy Analysis (NCPA), Policy Backgrounder No. 159, Retrieved December 14, 2007, from NCPA Web site: <www.ncpa.org/pub/bg/bg159/>.

E85.whipnet.net, (2007). E85. Retrieved February 17, 2008, from Methanol - M85 Fuel Web site: <http://e85.whipnet.net/yellow/m85.html>

Energy Information Administration (EIA). (2007). International Energy Outlook 2007. (Chapter 3, DOE/EIA-0484). Washington, DC; Government Printing Office. Retrieved February 27, 2008, from EIA Web site: <www.eia.doe.gov/oiaf/ieo/oil.html>.

Energy Information Administration (EIA). (2008). Petroleum Navigator. Washington, DC; Government Printing Office. Retrieved February 27, 2008, from EIA Web site: <http://tonto.eia.doe.gov/dnav/pet/hist/mg_rco_usw.htm>.

Environmental Engineering Science and Management (EESM): Concentration in Green Design [Brochure]. (2007). Pittsburgh, PA: Carnegie Mellon.

Graedel, T. E., and B. R. Allenby (2003). Industrial Ecology, Englewood Cliffs, NJ: Prentice Hall, 2nd edition.

Green Technology, (2007). Green Technology - What is it?. Retrieved February 17, 2008, from Green Technology Web site: <www.green-technology.org/what.htm>.

Hicks, L. (Ed.). (2007). Ethanol Transportation in Pipelines. Proceedings from Interagency Committee on Alternative Fuels and Low Emission Vehicles (INTERFUEL) Committee Meeting. Washington, DC.

Karbuz, S. (2007, February 17). US Military Oil Pains. Retrieved March 18, 2008, from Energy Bulletin Web site: <www.energybulletin.net/26194.html>.

MacLean, H. L., & Lave, L. B. (2002). Evaluating automobile fuel/propulsion system technologies. ScienceDirect. 29, 1-69.

Maynard, M. (2007, November 14). Ford Chairman Says New Fuels Are Developing Too Slowly. *New York Times*. Retrieved November 13, 2007, from NY Times Web site: <www.nytimes.com/2007/11/14/business/14ford.html?_r=2&ref=business&oref=slogin&oref=slogin>.

Moore, R. B., & Raman, V. (1998). Hydrogen Infrastructure for Fuel Cell Transportation. Int. J. Hydrogen Energy. 23, 617-620.

NASA, (2007). SBIR/STTR Appendices. Retrieved March 29, 2008, from Small Business Innovation Research Web site: <www.sbir.nasa.gov/SBIR/sbirsttr2007/solicitation/appendix_B.pdf>.

National Biodiesel Board, (2008, January 25). Commercial Biodiesel Production Plants. Retrieved February 17, 2008, from National BioDiesel Board Web site: <http://www.biodiesel.org/pdf_files/fuelfactsheets/Production_Capacity.pdf>.

Office of the Inspector General. (2002). DoD Alternative Fuel Vehicle (D-2003-25). Arlington, VA; Government Printing Office.

Offshore Minerals Management (2007). *Alternative Energy: Definitions*. Washington, DC. U.S. Department of the Interior.

Ogen, J. M., Steinbugler, M. M., & Kreutz, T. G. (1999). A comparison of hydrogen, methanol and gasoline as fuels for fuel cell vehicles: implications for vehicle design and infrastructure development. *Journal of Power Sources*. 79, 143-168.

Sandia Corporation, (2006). Homogeneous Charge Compression Ignition Fundamentals. Retrieved February 17, 2008, from Combustion Research Facility Web site: <http://public.ca.sandia.gov/crf/research/combustionEngines/EGR.php>.

U.S. Army. (2004), The Army Strategy for the Environment): Sustain the Mission. Secure the Future [Brochure]. Washington, DC.

U.S. Census Bureau, (2008, 28 January). Gasoline Stations. Retrieved March 18, 2008, from Industry Statistics Sampler Web site: <www.census.gov/econ/census02/data/industry/E447.HTM>.

U.S. Department of Energy. (2007). Alternative Fuels. Retrieved February 17, 2008, from Web site: <www.fueleconomy.gov/feg/current.shtml>.

U.S. Environmental Protection Agency. (2002). Clean Alternative Fuels: Fischer-Tropsch. Retrieved February 17, 2008, from Transportation and Air Quality Web site: <www.eere.energy.gov/afdc/pdfs/epa_fischer.pdf>.

U.S. Geological Survey (USGS). (2000) World Petroleum Assessment 2000. (p.8). Washington, DC; Government Printing Office. Retrieved February 27, 2008, from: <http://energy.cr.usgs.gov/WEcont/chaps/ES.pdf>.

Internet URLs were valid at the time the cited material was retrieved.